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ABNORMAL MOVEMENT OF BASCULE BRIDGES

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INTRODUCTION

A common occurrance during summer heat spells in the northeastern part of the country is that movable bridges, and particularly bascule bridges, jam tight during opening or closing. This often results in a great inconvenience to the motorist and his family, eager and restless to get to the beach, who have become stuck in traffic in their overheated car until the local fire department arrives to hose down the bridge and get traffic moving again. As the family get on their way, the motorist fumes about the hot weather and blames the engineer for not designing the bridge properly for expansion due to heat.

But engineers do design bridges to accommodate expansion of the steel in hot weather and although the weather does play a part, it is not the main reason movable bridges jam. It is the particular type of a movable bridge, and the unique forces acting upon the approach spans, that is causing abnormal movement of the structure which results in the jamming of the bridge. And it is more than the jamming of the movable span, which causes merely inconvenience to the motorist and embarrassment to the operator, that should be a concern of the bridge engineer. The abnormal movement, if left unattended, could cause serious structural damage resulting in costly repairs. This paper will discuss these movements, citing several examples from the writer's personal experience, develop possible causes for and discuss the consequences of this movement and suggest methods to minimize and accommodate this movement.

BACKGROUND

Since the late 1960's -- in response to the tragic collapse of the Silver Bridge over the Ohio River -- U.S. engineers have undertaken a nationwide inventory and inspection program of all our bridges to determine if they are safe for public use. More than a million bridges have, so far, been included in the program and a valuable byproduct has been the chance this has given engineers to observe, compare and evaluate the behavior of previous designs, bridge types, details and construction materials. From this mass of collected and assembled data, some very important facts on bridge conditions have come to light and interesting methods of bridge rehabilitation developed.

As a participant in this program over the past 17 years, this writer has had the opportunity to be involved in the inspection and evaluation of several hundred bridges of all types and ages. Of all the problems observed, the one that has most caught the writer's attention has been the abnormal movements of the superstructure of movable bridges.

For this paper, abnormal movement is defined as the horizontal movement or creep of the approach structure inward towards the movable span. This movement is detectable at the expansion bearings of the fixed approach spans.

RESEARCH AND EXPERIENCE

A review of literature was made to determine if there had been any prior research on bridge movements. Two recent studies were uncovered, one survey conducted by the Transportation Research Board in 1975 and a second prepared by the Federal Highway Administration in 1985. Both of these studies dealt with fixed bridges. The studies showed that movements have been recorded for abutments and to some extent, adjacent piers. However, these studies showed that movement rarely occurred past the first pier away from the abutment and stated that the percentage of bridges where movement was observed was quite small compared with total number of bridges surveyed. This compares favorably with this author's observations over the past 17 years of bridge inspection.

In comparison to fixed bridges, this writer's observations of movable bridges shows this movement to be more common and extend across the entire length of the structure. Of over thirty movable bridges which this writer has personally inspected or reviewed the inspection report, 75 percent showed evidence of this abnormal movement. Although observed on swing and vertical lift structures, this movement was more commonly found on single or double leaf bascule bridge, which make up the bulk of the movable structures. This movement was also more likely to be found on highway bridges than on railroad structures. Following are three examples from this writer's experience illustrating this abnormal movement.

Bridge No. 1. This structure, built in 1927, is a 480-foot-long six span highway bridge consisting of a 80-foot-long single leaf bascule span flanked on both ends by concrete encased steel girder approach spans. (See Figure 1)

Significant abnormal movement of the approach structure has occurred on this bridge. The movement is observable at the expansion bearings located at Piers 1, 2 and 3. The original plans for this bridge show that these bearings consist of a sliding bronze plate sandwiched between two steel castings.

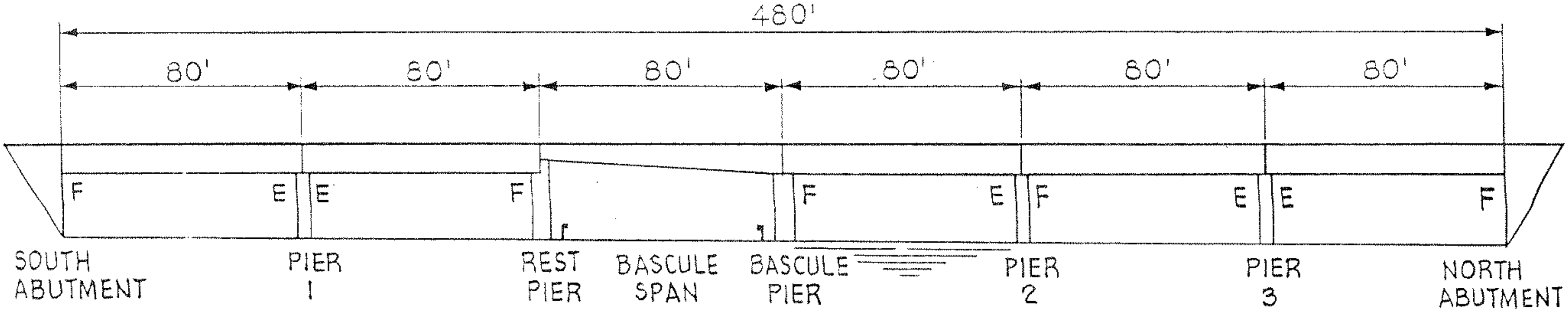

FIGURE 1 - ELEVATION OF BRIDGE NO. 1

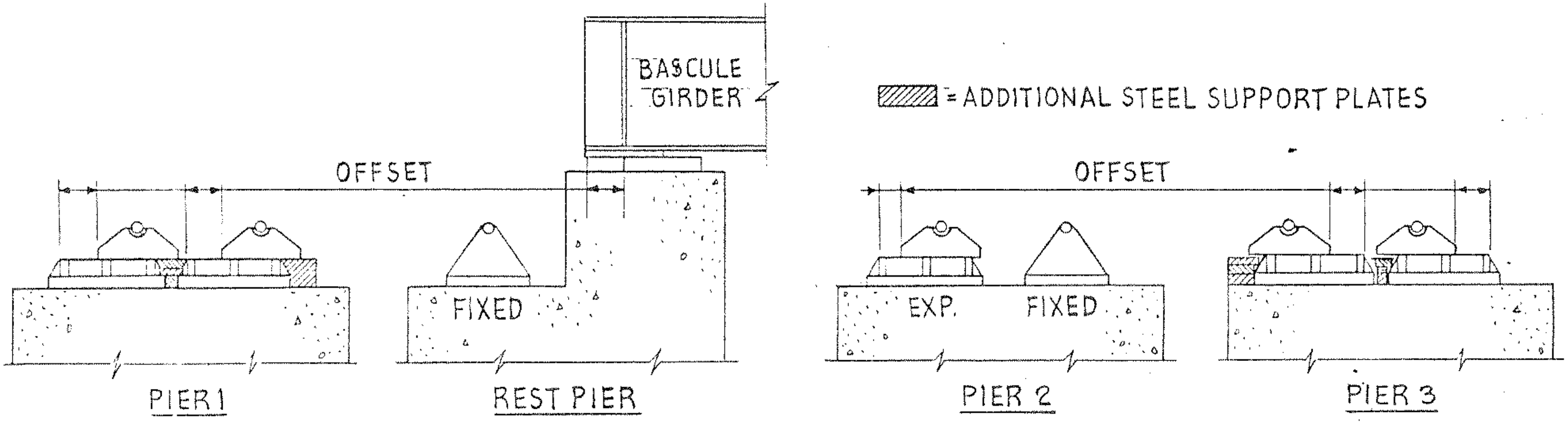

FIGURE 2 - POSITIONS OF EXPANSION BEARINGS ON PIERS

Considerable movement had already taken place when this writer first inspected this bridge in 1981. Field measurements taken over the past 6 years indicates that this movement still persists. Measurements taken during subsequent inspections in 1985 and 1987 showed additional movements of up to 3/4 inches has occurred since 1981. At some locations, where bearing offsets are large, plates have been added to extend the bottom plate as the upper plate was starting to drop off the casting below. Figure 2 shows the movement that has occurred at these bearings.

In this case, it is theorized that the movement started at the approach spans adjacent to the abutments at either end of the bridge, causing the upper plate of the expansion bearings for these spans at Piers 1 and 3 to slide inward towards the bascule span until the end of the span butted tight against the adjacent span at the roadway joint above. Movement then continued with the upper plates of both adjacent expansion bearings sliding inward together towards the movable span.

At Pier 2 of the north approach, where the inward end of the second approach span is fixed, the movement of the approach structure is pushing the pier inward, causing the lower plate of the expansion bearing of the adjacent third approach span to slide out from under the upper plate. This movement will continue here until the end of adjacent spans are butted together at the roadway joint above. Then the forces of movement will begin to act on the joint above the bascule pier.

On the south approach, the bearing at the inward end of the approach section are fixed atop the rest pier. The movement here is thus pushing the pier inward, causing the top section to lean noticebly. In turn, the toe end of the girders of the bascule span now overhang their bearings at the rest pier by at least six inches. As a result, the fingers for the steel roadway joint above have had to be cut back several times to prevent jamming of the joint. There is also an on-going problem with properly seating the bascule span and aligning the locks at the toe, which most likely is caused by this movement.

Of interest, an older railroad bascule bridge of similar length, which runs parallel and adjacent to this bridge, shows no evidence whatsoever of this abnormal movement.

Bridge No. 2. This highway bridge, built in 1950, is a 500-foot-long, seven span structure consisting of a 70-foot-long single leaf bascule span flanked by rolled steel stringer approach spans (see Figure 3)

Atop Piers 1 and 6, the first piers in from the abutments at either end of the bridge, the rocker-type bearings for adjacent approach spans are all leaning inward towards the movable span. Both sets of bearings have been rocked into their maximum position and appear to be locked in place and no longer able to function for thermal movement, the rockers of the first approach spans in full expansion and the rocker of the adjacent approach spans in full contraction. (see Figure 4)

Perhaps to compensate for this movement at the bearings, Piers 1 and 6 are observed to be leaning outward towards the abutments. Pier 1 leans about

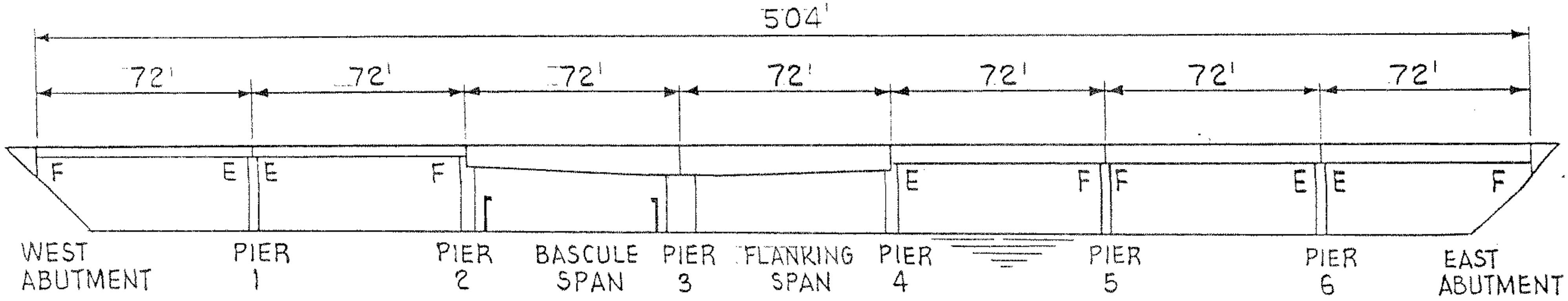

FIGURE 3 - ELEVATION OF BRIDGE NO. 2

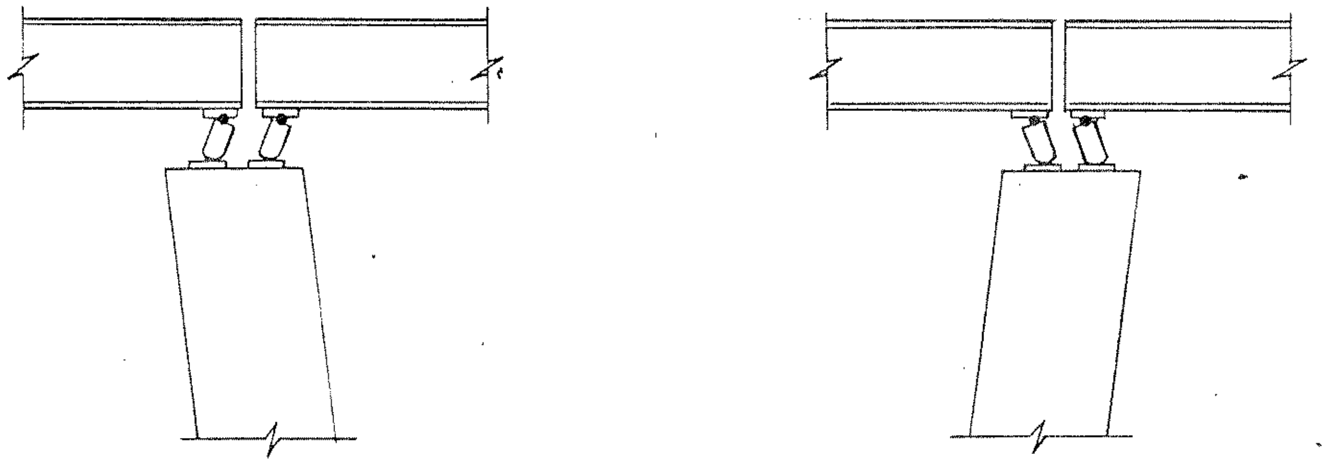

FIGURE 4 - DETAIL OF MOVEMENT AT PIERS 1 AND 6

4 inches horizontally over its 30 foot height while Pier 6 is leaning about 1½ inches.

Some movement is also observed at Pier 4 where the expansion bearings of the approach span are also leaning inward towards the movable span. At the toe of the bascule span over Pier 2, the bearings for the bascule span do not seat properly, nor are the span locks tight, problems that may be a result of this movement.

Bridge No. 3. This last structure is a 700-foot-long, seven span highway bridge built in 1949. The bridge consists of a 160-foot-long double leaf bascule span flanked by steel plate girder approach spans (see Figure 5).

As shown in Figure 6, the rocker type bearings of adjacent approach spans at Piers 1, 3 and 6 were observed to be leaning excessively in the expansion position. Measured leans were much greater than would have been expected for normal expansion. The roadway joints above these piers, which have an original design opening of 1-1/8 inches, were noted to be butted tight in warm weather and only opened up ½ inch in cold weather.

These three examples show it is the abnormal movement of the approach spans that is the major contributer to the jamming of the joint of the movable span, and not temperature alone. Many times, when a bascule leaf gets jammed, the highway maintenance crew will be out the next day to cut back the fingers of the joint so that the bridge does not jam again. However, more times than not, do to the continuing movement of the approaches, the movable span jams up again a few summers later.

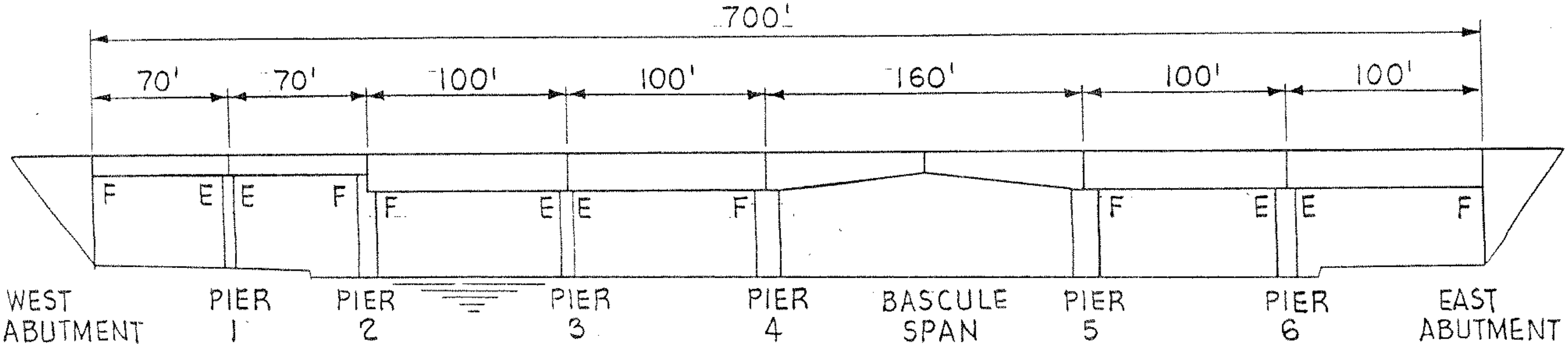

FIGURE 5 - ELEVATION OF BRIDGE NO.3

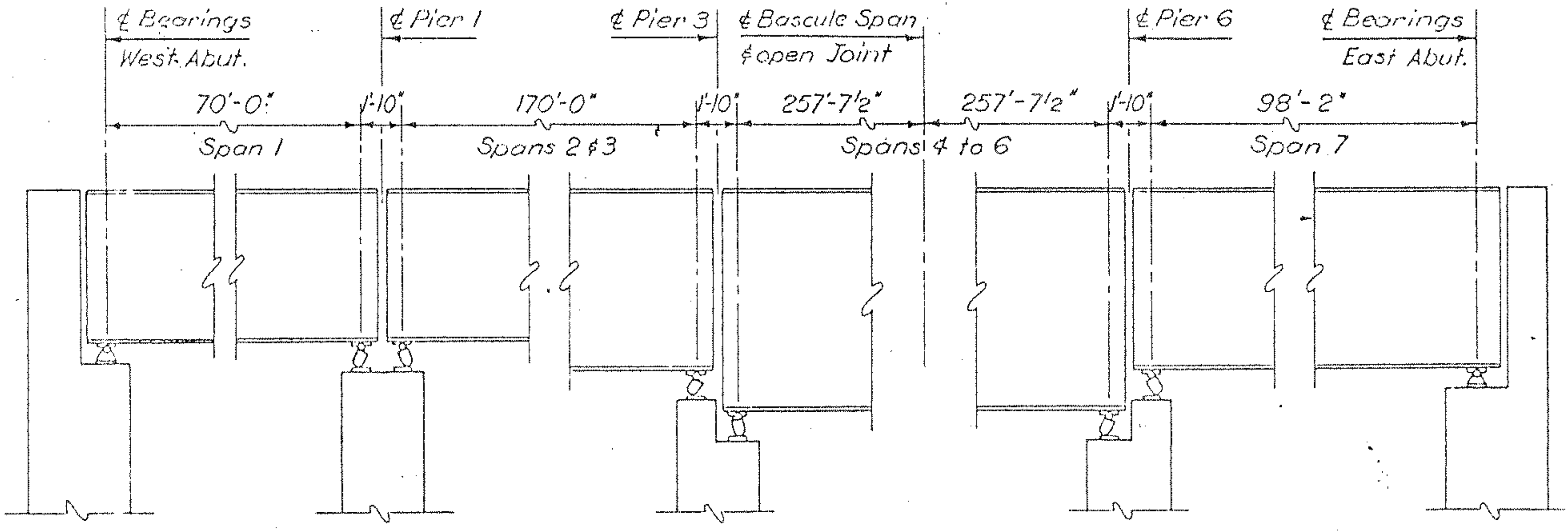

FIGURE 6 - POSITION OF EXPANSION BEARINGS

But the jamming of the movable span is not the main point of concern to this writer. It is the movement of the approach span expansion bearings which is of major consequence. These bridge bearings are one of the most critical members of the bridge structure. In addition to transferring the heavy loads of the bridge superstructure and the traffic it carries to the substructure and foundations, they are also called upon to accommodate the normal thermal expansion and contraction that takes place in the bridge due to changes in temperature. Thus, these are heavily loaded elements which are subjected to constant movement. Although, in many cases, they are often poorly maintained and constantly exposed to the elements, they are expected to last the lifetime of the structure.

However, when this abnormal movement occurs, where the bearings are sliding off these lower castings, or rocker have been tilted until they have locked up, not only can the normal thermal movements no longer be accomodated, but stresses due to eccentric and point loading on the casting build up which could cause overstressing of both the bearing and pier cap below. If left unchecked, these movements could conceivably lead to the ultimate failure of the bearing, resulting in a localized failure and disruption of traffic, or worse, a total collapse of a section of the bridge. Although this writer knows of no such failure, events of recent years indicate that bridges may not be getting the proper level of inspection required.

In addition to these expansion bearing, other damage and distress is also occurring to castings and anchor bolts of fixed bearings, piers which are now leaning, roadway joint areas that are butted together and the toe end of the bascule span where bearings are not properly seating and span locks are misaligned.

CAUSES

As already stated, this abnormal movement has been more commonly observed on movable bridges than on fixed bridges, and it is this very fact that leads to an understanding of why it occurs. Surely, movable bridges are affected by the same forces that act to cause movements in a fixed structure; earth pressure due to longitudinal forces and differential settlement. But, as this writer believes, it is the differences between fixed and movable structures with results in the significant abnormal movements observed throughout the length of the movable structure.

First, consider the difference in the bridge structures themselves. In a fixed bridge, one can imagine that the structure is longitudinally continuous over its entire length from one abutment to another and thus, for reasons not entirely clear, movements are cancelled out or diminished not far from the abutments. On the other hand, a movable bridge, by its very nature, has a longitudinal discontinuity at the movable span. Thus, particularly when the span is open, and in some cases, when the span is in the closed position, there are no offsetting reactions from either end of the bridge.

This will also explain why this abnormal movement has been more likely observed on a bascule type structure than the other common movable types with a swing or vertical lift span where the movable span is more apt to act like a fixed span in the down position. For the swing span type, the downward reaction when driving the wedges at both ends of the span tends to keep the span down on the top of the rest piers. In a similar fashion, the weight of vertical lift span, along with the unbalance of the ropes, tends to keep the span seated on its bearings atop the tower piers.

On a bascule bridge, however, the longitudinal continuity of the structure is usually broken regardless of whether the span is in the open or closed position. On a double leaf bascule, this is very clear, as there is no longitudinal connection between the gap at the toe of adjacent leaves, but merely a shear lock which only function is to transfer vertical loads between leaves. This may not be as evident on the single leaf bascule, although the writer believes that this discontinuity also exists with the span in the closed position. Commonly, highway bascule spans are balanced over a trunnion with the greater weight just as likely to be on the counterweight side than the span side, resulting in a uplifting force on the bearings at the toe end of the span. Very often, this writer has observed the failure of the single leaf span to properly seat and lock into place at the rest pier bearings. More likely than not, the leaf is riding high and bouncing under traffic impact.

Secondly, the movable structure is subjected to significant longitudinal braking forces not experienced on fixed bridges. Imagine how infrequently vehicles brake to a stop on a fixed structure, only on the rare occasion of an accident or other traffic tie-up. But on a movable bridge, particularly one carrying highway loading, vehicles are constantly stopping whenever the bridge is to be opened. This longitudinal braking force not only acts on the earthen fill behind the abutments, but on long structures like the three examples cited previously where the traffic gates are on the structure itself, also on the approach superstructure. At busy bridges, with opening of upwards to 4,000 and 6,000 a year, which is not uncommon along the Atlantic Coast, these braking forces can be very significant.

The significance of the effect of the longitudinal braking forces as a factor in causing this abnormal movement can be verified by this writer's observations of the lack of this movement at movable bridges carrying solely railroad loads. Rarely will a train be brought to a stop to allow a railroad bridge to open, thus there is an absence of braking forces here. An example is the railroad bridge directly adjacent to Bridge No. 1. Although of similar length and type (single leaf bascule) no evidence of abnormal movement was noted at this particular structure.

DESIGN CODES

The original AASHTO design criteria for determining longitudinal braking forces, first published in 1931 specified using 10 percent of the live load on the structure, taken 4 feet above the top of the roadway. In 1941 specification, the longitudinal force was reduced to 5 percent of the live load, using lane loads, with concentrated load for moment, and no impact. The force was assumed to be based on all traffic headed in the same direction and reductions in load intensity (number of traffic lanes loaded) was to apply. This was also the first specification that the longitudinal force due to friction at expansion bearings was to be provided for in the design. In 1961, the specification was further modified to have the force taken 6 feet above the roadway surface. It remains this way in the current 1983 specification.

A check of the sliding plate bearings for Bridge No. 1 and the rocker bearings of Bridges No. 2 and No. 3 show that 5 percent of the AASHTO longitudinal design force is not high enough to cause these bearings to move.

The ASCE committee on Loads and Forces on Bridges in the July 1981 ASCE Structural Division Journal recommended that the longitudinal load due to braking in one lane shall be increased to 80 percent of the load of the AASHTO design truck while the coincident longitudinal load in each other traffic lane remain at 5 percent of the lane load, including concentrated load for moment. The longitudinal force is to be applied 6 feet above the roadway.

The commentary to this recommendation interestingly noted that the current longitudinal force used by AASHTO, 5 percent of lane loading, was far less than longitudinal loads required by many other codes. Computing an equivalent braking load for these other codes resulted in forces 6 to 25 times greater than the current AASHTO specified load. The ASCE recommendation calls for a load almost 15 times greater than the currently used load.

The 1983 Ontario, Canada Highway Bridge Design Code, for instance, calls for a design braking force of either 160 KN (36 kips) which is 23 percent of the OHBD truck gross load of 700 KN (157.5 kips or more than twice the AASHTO design truck load) or 10 percent of the lane load of as much 10 KN per meter (0.685 kip/ft) with a reduction of 25 percent if two adjacent lanes are loaded.

The commentary to both the 1981 ASCE recommendations and the 1983 Ontario Highway Bridge Design Code cite evidence indicating that the braking forces can be as much as the weight of the vehicle itself. They both note however that the exertion of this maximum braking load is unlikely and the specified loading is thus a reasonable compromise.

If either the ASCE recommended longitudinal braking force of 80 percent of the design truck or an equivalent Ontario longitudinal loading is substituted for the current AASHTO braking force of 5 percent of the lane load, the force would overcome the friction at the bearings on each of the bridges cited. Figure 7 summarizes these forces.

RECOMMENDATIONS

Based on this writer's observations and research on this subject of abnormal movements in movable bridges, the following recommendations are put forth:

1. Survey movable bridges nationwide to determine the extent of this abnormal movement.

   Prior to the preparation of this paper, the writer sent out a brief questionnaire to a few State transportation departments across the country, but with little positive results. At this time, a detailed survey should be undertaken, using the vast data collected and computerized during the nationwide bridge inventory and inspection program, to determine how widespread this problem is and whether it is more likely to occur in certain climates or regions of the country, or to certain particular bridge types. States or agencies

FIGURE 7

SUMMARY OF FORCES

	BRIDGE #1	BRIDGE #2	BRIDGE #3
Span Length	80'	72'	100'
Type of Bearing	Sliding	Rocker	Rocker
Force Needed to overcome friction	57.3 k	9.4 k	21.8 k
CODE*:			
AASHTO	7.7 k	7.2 k	9.0 k
ASCE	61.5 k	61.2 k	62.1 k
Ontario	82.2 k	74.0 k	102.7 k

* AASHTO - 5% of lane load X 2 lanes loaded.

ASCE - 80% of design truck load plus adjacent lane load.

Ontario - 23% of design truck load or 10% of lane load all reduced by 25% for two lanes loaded.

with a large number of movable bridges should be contacted directly to discuss this movement.

2. Revise AASHTO specification.

Further study and consideration should be given to revising the current AASHTO Standard Secifications for Highway Bridges to increase the percentage of live load used for computing longitudinal braking forces. If it is felt a general change is not warranted, a modification should at least be made for bearings of approach spans which are part of movable structures.

3. Retrofit of existing bridges.

Those existing structures on which this movement is observed should be rehabilitated to minimize or safely accommodate this movement. Bearings should be reset and base plates moved or enlarged. If possible, bearings should be replaced with types which can better accommodate this movement. Roadway joint areas should be opened up to prevent further damage. Also install tie backs at abutments to resist braking loads on the roadway approach embankment.

4. Design new movable structures considering this movement.

In preparing plans for new movable structures, particularly bascule bridges, provision should be made to minimize this movement. Abutment areas, expansion bearings and piers should be designed to resist realistic longitudinal braking forces. Joints should be detailed to accommodate some movement, particularly at the movable spans.

CONCLUSIONS

Abnormal movement in which the approach spans move inward towards the movable span, occurs on movable structures, particularly bascule-type bridges. In addition to being a major cause of the jamming of the movable span, this movement causes serious problems at the expansion bearings and joints of the structure. The seriousness of this problem should be studied further and revisions to the AASHTO specification for determining longitudinal braking forces be considered. Finally, retrofits of existing bridges where this movement is occurring should be undertaken and this movement should be considered in the design of new movable bridges.